NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

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POWERING CHARACTERISTICS OF A LOW-BLOCK DISPLACEMENT HULL FORM IN HEAD SEAS

by

Hugh Y.H. Yeh
Heinrich Schutz
Paul Plaia

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SHIP PERFORMANCE DEPARTMENT
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June 1973

Report 4059

POWERING CHARACTERISTICS OF A LOW-BLOCK DISPLACEMENT HULL FORM IN HEAD SEAS

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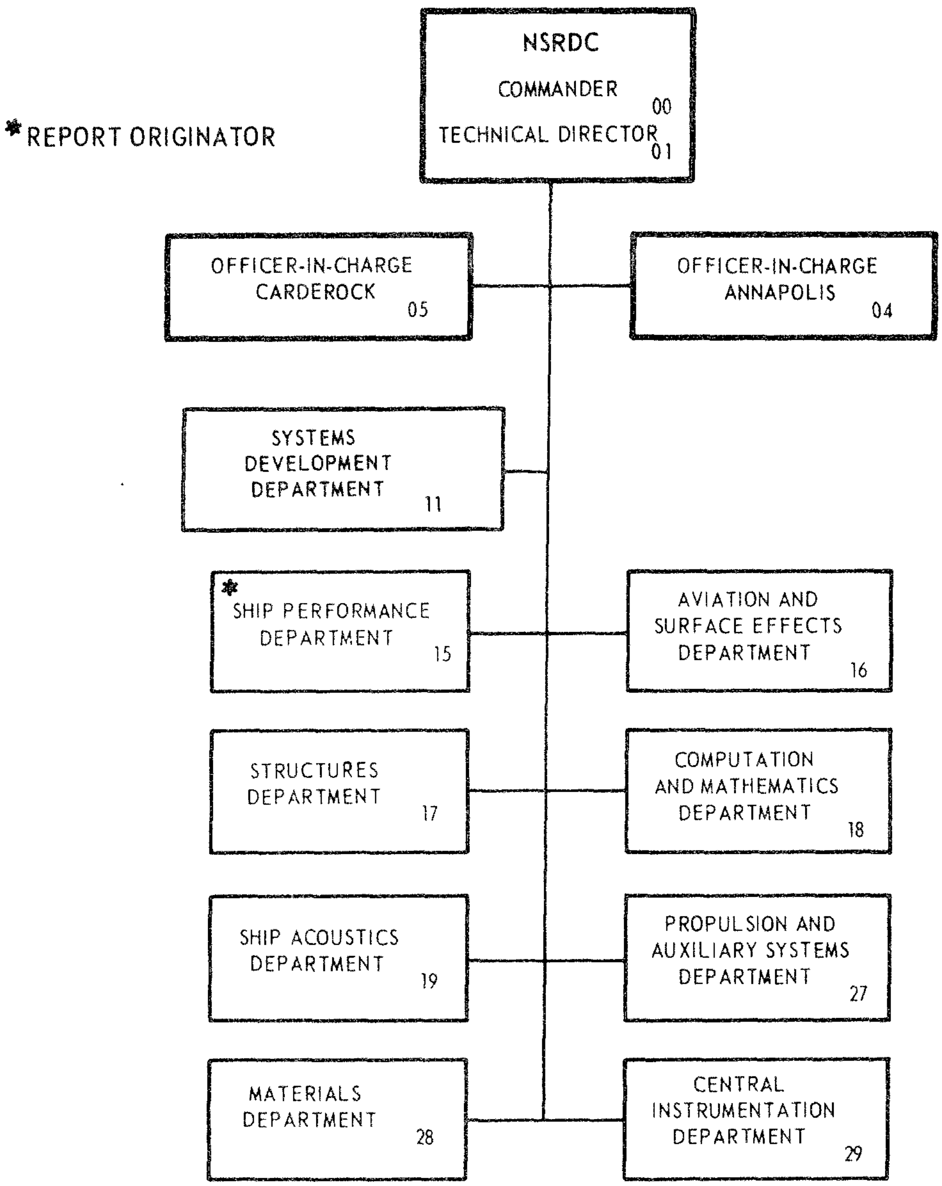

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ABSTRACT

Ship powering characteristics in a seaway were investigated for the model of a low-block coefficient, displacement-type hull in both regular and irregular head seas. The increase in power required to maintain speed was predicted by using both the regular-wave and the irregular-wave test results and these predictions were compared. Results indicate that when used within certain limits, the assumption held that added drag is proportional to wave height squared.

ADMINISTRATIVE INFORMATION

This work was authorized by the Naval Ship Systems Command under the General Hydromechanics Research Program of the Naval Ship Research and Development Center (NSRDC). Funding was provided under Subproject SR-023-01-01.

INTRODUCTION

One of the major problems facing a naval architect is to ensure that the new ship he is designing will maintain a certain speed. In order to do this, he must determine the horsepower needed to drive his design at the specified speed and, consequently, he must have methods for predicting the powering characteristics of related hull forms. In the past, these predictions have been based on data from specific model tests or on the results of methodical model-series tests in calm water. Obviously, ships will seldom, if ever, operate in such conditions. Usually, an arbitrary amount of horsepower is added to the calm-water requirement to compensate for the increased power needed to overcome added resistance due either to rough water or to bottom fouling. This procedure has been followed mainly because no reasonable technique has been available for determining the effects of sea conditions on ship powering.

In 1953, however, Pierson and St. Denis[1] introduced the use of a statistical representation of sea conditions and a linear superposition technique. This prediction method gave a good approximation of ship-motion responses. More recently, seakeeping basins have been built in the United States and abroad and ship motion studies have advanced considerably. It is only natural that the same techniques are now being considered for determining the added power required in a seaway.

Most investigators maintain that power increases are due mainly to increased resistance, i.e., that all associated propulsive coefficients remain the same. Therefore, if we know the added resistance of a ship in a

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[1]Pierson, W.J., Jr. and M. St. Denis, "On the Motion of Ships in Confused Seas," Trans. SNAME, Vol. 61, pp. 280-357 (1953).

seaway, we can obtain the power required for a sea condition by applying calm-water propulsive coefficients to the added resistance. As a consequence, most theoretical papers in this area deal only with added resistance; those most often referred to are by Maruo.[2-4] The Maruo theory states that added resistances are essentially proportional to the square of wave height. Experiments have shown that this is generally true for merchant ships but that the theory is questionable when applied to low-block-coefficient ships.[5-7]

The purpose of the present study was to obtain more experimental data on the powering performance in waves of a low-block-coefficient hull form and to determine the applicability of the Maruo theory for such forms. If, in fact, the "square law" does not hold, then the characteristics of the added-power demands were too defined and test procedures established for determining added power.

MODEL AND PROPELLER PARTICULARS

NSRDC Model 4360-1 was selected for the experiments. This single-screw, twin-rudder, low-block-model with bilge keels was fitted with NSRDC Propeller 3448. The 18.182-ft model was constructed of wood to a linear ratio of 16.94; ship and model data are given in Figure 1. Tests were conducted for a ship design displacement of 1890 tons at a draft of 11.91 ft, even keel. The propeller characterization and open-water curves shown in Figure 2 represent a 12.5-ft diameter, five-bladed propeller.

A 5-ft model of the same hull had been tested at the University of California by Sibul.[5-7] It was anticipated that testing a larger scale model of the same hull would provide additional information on blockage effects.

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[2] Maruo, J., "The Excess Resistance of a Ship in Rough Seas," Int. Shipbuilding Prog., Vol. 4 (1957).

[3] Maruo, J., "Wave Resistance of a Ship in Regular Head Seas," Bulletin of the Faculty of Engineering, Yokohama National University, Vol. 9 (Mar 1960).

[4] Maruo, J., "The Theory of the Wave Resistance of a Ship in a Regular Seaway," Bulletin of the Faculty of Engineering, Yokohama National University, Vol. 6 (Mar 1957).

[5] Sibul, O.J., "Increase of Ship Resistance in Waves," University of California, Berkeley, College of Engineering Report NA-67-2 (Mar 1967).

[6] Sibul, O.J., "An Experimental Study of Ship Resistance and Motions in Waves–A Test for Linear Superposition," The University of California, Berkeley, College of Engineering Report NA-66-3 (Jan 1966).

[7] Sibul, O.J., "Ship Resistance and Motions in Uniform Waves as a Function of Block Coefficient," The University of California, Berkeley, College of Engineering Report Series 61, Issue 19 (Jun 1961).

TEST FACILITY

Experiments were conducted in the Harold E. Saunders Seakeeping Facility at NSRDC. This rectangular concrete basin is 240 ft wide by 360 ft long and has a water depth of 20 ft. Pneumatic wavemakers are located on adjacent walls of the basin, and both regular and irregular waves can be generated. Fixed bar-type concrete wave absorbers are installed along the opposite basin walls. A steel bridge spans the length of the basin and a model towing carriage operates along tracks hung on the underside of the bridge.

Regular waves are generated by setting the dome pressure and by regulating blower rate of revolution (which governs the wave height) and valve-opening period (which governs the wave length). The dome pressure and valve period can be controlled by preprogrammed tapes to produce random sea conditions.

METHODS AND PROCEDURES

Resistance and propulsion experiments were conducted in calm water and in waves. The parameters explored in the wave tests are outlined in Table 1.

TABLE 1 – TEST PROGRAM

Propulsion Experiments	Irregular Head Waves	F_n = 0.10, 0.20, 0.25, 0.30, 0.35 Sea State = 0, 5, 6
	Regular Head Waves	F_n = 0.10, 0.15, 0.20, 0.25, 0.30, 0.35 λ/L = 0.4, 0.8, 1.0, 1.2, 1.6, 2.0 ζ_W/λ = 0, 1/130, 1/110, 1/90, 1/70, 1/50, 1/30
Resistance Experiments	Regular Head Waves	F_n = 0.10, 0.15, 0.20, 0.25, 0.30, 0.35 λ/L = 0.8, 1.0, 1.2, 1.6 ζ_W/λ = 0, 1/130, 1/110, 1/90, 1/70, 1/50, 1/30

It was considered very important to obtain calm-water data in the same manner as rough-water data. Therefore, the calm-water portions of the experiments differed from traditional calm-water powering experiments in that an entirely free-running model was used. It was assumed that the increase in power due to waves did not differ greatly when the model was operated at ship propulsion point and model propulsion point; for simplicity, therefore, model propulsion points were used. Because the calm-water data were the basis of all rough-water experiments, runs in calm water were repeated several times (before, between, and after rough-water runs) to ensure an accurate reference for comparing results. Although the differences between all calm-water runs were small (within test accuracies), only tests conducted on the same day as the rough-water tests were used in the analysis to ensure that the condition of the model and the water temperature were unchanged.

Resistance experiments were conducted with constant tow forces, and the carriage speed was set to keep pace with the model. Model speeds were then obtained by combining the carriage speed with the model surge record.

The model was free-running for propulsion experiments in waves and in calm water except for power supply wires and instrumentation leads. These were attached so as to impose a minimum amount of force on the model. All experiments were carried out in head seas only. The actual wave heights were measured by a sonic wave probe located one model length ahead of the model; they were recorded continuously during the experiment to provide instantaneous data on sea conditions. Heave accelerations were measured by an accelerometer located in the model, and data were integrated twice to obtain heave amplitude; positive heave was considered to be upward. Pitch angle was measured by a pitch gyroscope and the bow-down position was assumed as positive. In the pitch and heave calculations, the phase angles express the lead with respect to maximum wave elevation at midship.

Yaw, sway, and roll were measured, but the results were not analyzed since the measured magnitude is small in head-sea conditions. Model surge was detected by a sonic probe and was combined with carriage velocity to yield the velocity of the unsteady model. The model surge signal was also fed back to the propeller drive system to keep model speed constant; therefore, surge was generally very small and could be neglected. Yaw and sway output signals were used to control the rudder servo. This arrangement kept the model on course with minimum rudder angles (usually less than a couple of degrees). Relative bow motion was measured by a sonic probe at Station 1. Propeller thrust and torque were measured by reluctance magnetic gages, and carriage speed and propeller shaft speed were monitored with slotted-disk, magnetic-pickup devices.

All test data were recorded simultaneously on analog tape and later converted to digital form for analysis. Some information was also recorded on strip chart recorders and RMS voltmeters for monitoring during the experiments.

RESULTS AND DISCUSSION

RESISTANCE

The results of resistance experiments conducted at constant tow forces were compared with those of other experiments[8,9] in which the model was restrained in surge motion and even forced to surge. No significant differences were found in the results of the two types of experiments. Therefore, since the restrained-model experiment is easier to conduct, the technique in which the model is restrained in surge motion should be pursued more fully in resistance experiments.

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[8] Wahab, R. and L.W. Moss, "On the Added Drag of Destroyers in Regular Head Waves," NSRDC Report 3704 (Aug 1971).

[9] Sibul, O.J., "Progress Report for NSRDC GHR Program," University of California, College of Engineering (Dec 1970).

No results are reported for $\lambda/L = 0.4$ and $\lambda/L = 2.0$ because the differences between results of calm-water and wave tests were sufficiently small to be within instrumentation accuracy.

PROPULSION

Regular-Wave Experiments

As stated in the introduction, one of the main objectives of this study was to investigate the applicability of the "square law" for predicting the added resistance in waves of low-block-coefficient hulls. Therefore, several wave heights were investigated for each wave length and speed (see Table 1). Figures 3-8 show how the various parameters were affected by changes in wave height. The straight lines on these figures indicate the slope of 2. If the square law holds, then a line drawn through all data points should form a line which coincides with or is parallel to this line.

It can be seen that this was not the case. If we curve-fit the data by the least-squares method, the exponents of the lines are between 1.5 and 3 (Figure 9). However, if we eliminate the extreme conditions as designated in Figure 10 (that is, omit the waves which are too small or too large), then the majority of the data points fit the square law fairly well, at least for engineering purposes. This procedure can be justified by the argument that because the power required in calm water differs only slightly from that required in very small waves, the accuracy of such differences is therefore questionable. On the other hand, very large waves cause shipping of green water and the emergence of forefoot or propeller and will obviously lead to a complicated nonlinear domain. Accordingly, all the transfer functions were determined without the extreme data and using the slope-2 lines which appeared to best fit the data points. These are presented in Figures 11-14 as functions of the frequency of encounter for each Froude number.

Irregular-Wave Experiments

Model experiments were conducted at five speeds for each of two sea conditions (States 5 and 6, with significant wave heights of 10 and 16.9 ft, respectively). For each condition, 30 min of (equivalent full-scale) data were obtained in order to have sufficient sampling for a statistical analysis. Because of the limited length of the tank, this entailed several crossings for many of the conditions. The measured sea spectra are given in Figures 15 and 16.

Prediction of Added Power in Random Seas

The power required in random waves was obtained from regular-wave data by applying the theory of linear superposition and integrating the products of the transfer functions (Figures 11-14) and the sea spectra (Figures 15 and 16). Figure 17 shows a typical example of these products. The results of the integration

are shown as lines in Figure 18 (open circles indicate the data obtained from irregular-wave tests). The details of this method are given by Gerritsma et al.[10] For this particular case, the agreement was very good.

CONCLUSIONS

1. The "square law" can be applied to low-block-coefficient hull forms within certain limitations of wave height.
2. Care should be exercised in using the results of model experiments to obtain the transfer functions for increase of power or drag in waves. The waves should be large enough to generate significant differences of power or drag over calm-water results, but should not be large enough to create violent hull motions. This is in contrast to motion study experiments which require only that waves should be small and stay in the linear range.
3. Additional data on powering requirements in waves are needed to define the applicable limits of the "square law."

ACKNOWLEDGMENTS

The authors are grateful to Messrs. R. Long and D. Huminik for instrumentation support and to Mr. G. Rossignol for computer analysis of the data.

[10]Gerritsma, J. et al., "Propulsion in Regular and Irregular Waves," International Shipbuilding Progress, Vol. 8, No. 82 (Jun 1961).

APPENDAGES :

DIMENSIONS			LWL COEFFICIENTS			
	SHIP	MODEL	C_B	.485	C_{WF}	.619
LENGTH (LWL) FT	308.00	18.182	C_P	.604	C_{WA}	.912
LENGTH (LBP) FT.	308.00	18.182	C_X	.803	L_E/L	.575
BEAM (B_X) FT	36.52	2.156	C_W	.754	L_P/L	0
DRAFT (H) FT.	11.91	0.716	C_{PF}	.578	L_R/L	.425
DISPL. IN TONS	1892 S.W.	0.3784 F.W.	C_{PA}	.674	L/B_X	8.433
WETTED SURF. SQ. FT.	12120	42.2	C_{PE}	.615	B_X/H	3.011
DESIGN V IN KTS.			C_{PR}	.592	$\Delta/(0.01L)^3$	64.76
LCB_{LWL} = 0.515 AFT OF F.P.			C_{PV}	.797	$S/\sqrt{\Delta L}$	15.88
LCF_{LWL} = 0.567 AFT OF F.P.			C_{PVA}	.557	f	0.028
WL ENTRANCE HALF ANGLE = $7\frac{1}{2}^{\circ}$			C_{PVF}		f	1.100

RADIUS OF GYRATION = 0.25L

VCG = 12.94 FT

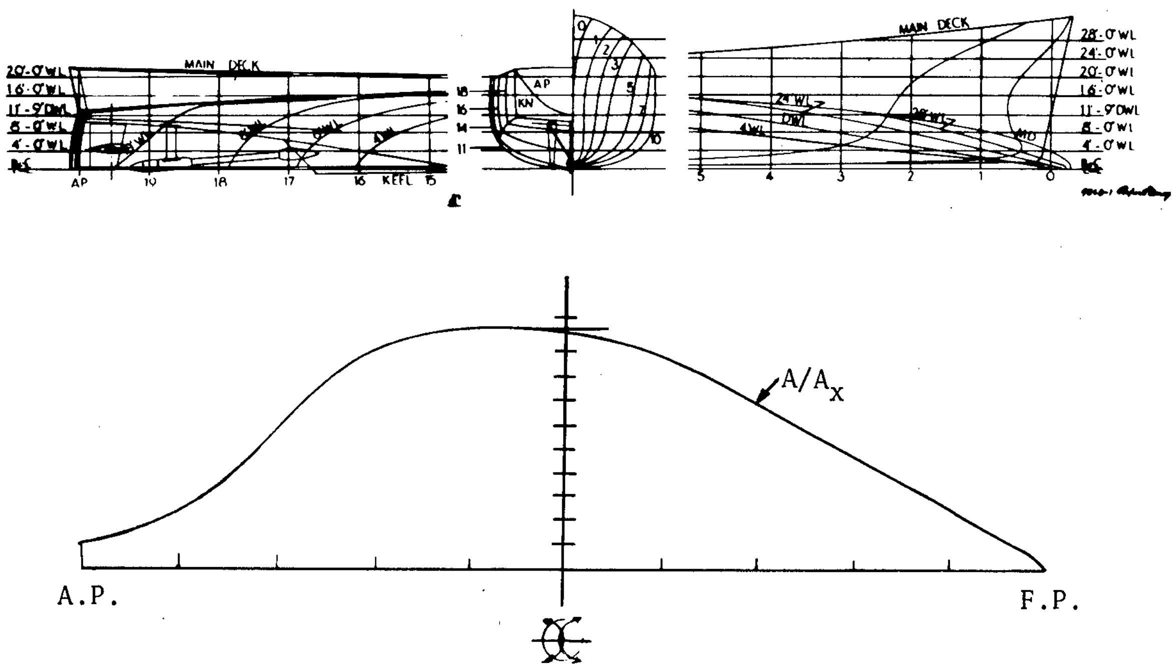

Figure 1 – Hull Characteristics of Model 4360-1

REYNOLDS NO., $R_e = \frac{b_{.7}\sqrt{V_a^2 + (.7\pi n d)^2}}{\nu}$
THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 d^4}$
TORQUE COEFFICIENT, $K_q = \frac{Q}{\rho n^2 d^5}$
SPEED COEFFICIENT, $J = \frac{V_a}{nd}$
EFFICIENCY, $e = \frac{TV_a}{2\pi Q n} = \frac{K_t}{K_q} \times \frac{J}{2\pi}$

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_a = SPEED OF ADVANCE
ν = KINEMATIC VISCOSITY
d = DIAMETER
p = PITCH
ρ = DENSITY OF WATER

NUMBER OF BLADES	5
EXP. AREA RATIO	0.778
MWR	0.304
BTF	VAR.
p÷d	1.054
DIAMETER	8.855 ins.
PITCH	9.333 ins.
ROTATION	R. H.
TEST V_a	2.2 - 6.6 Kts.

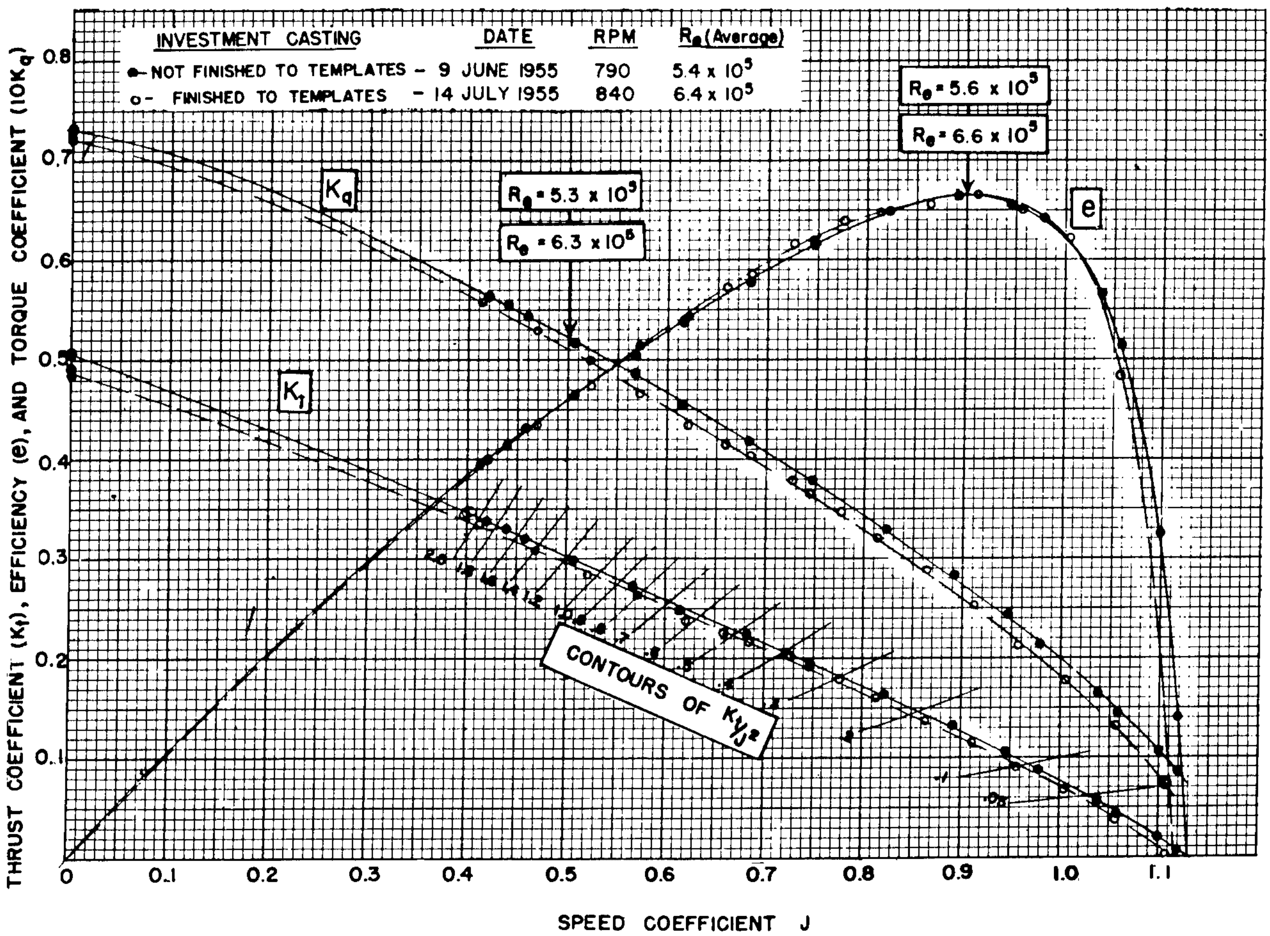

Figure 2 – Open-Water Characteristics of Propeller 3448

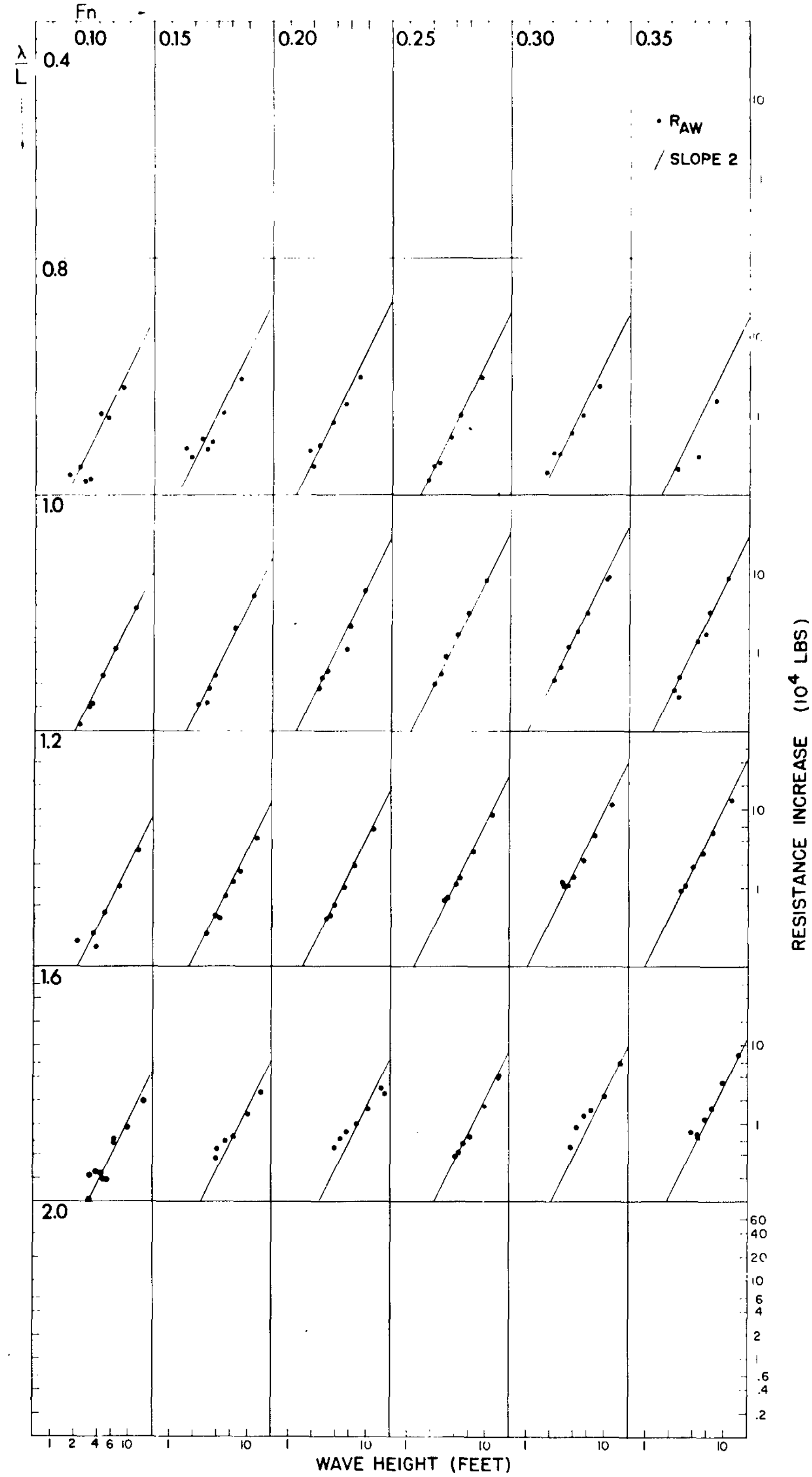

Figure 3 – Added Resistance versus Wave Height for Constant Wave Length and Froude Number

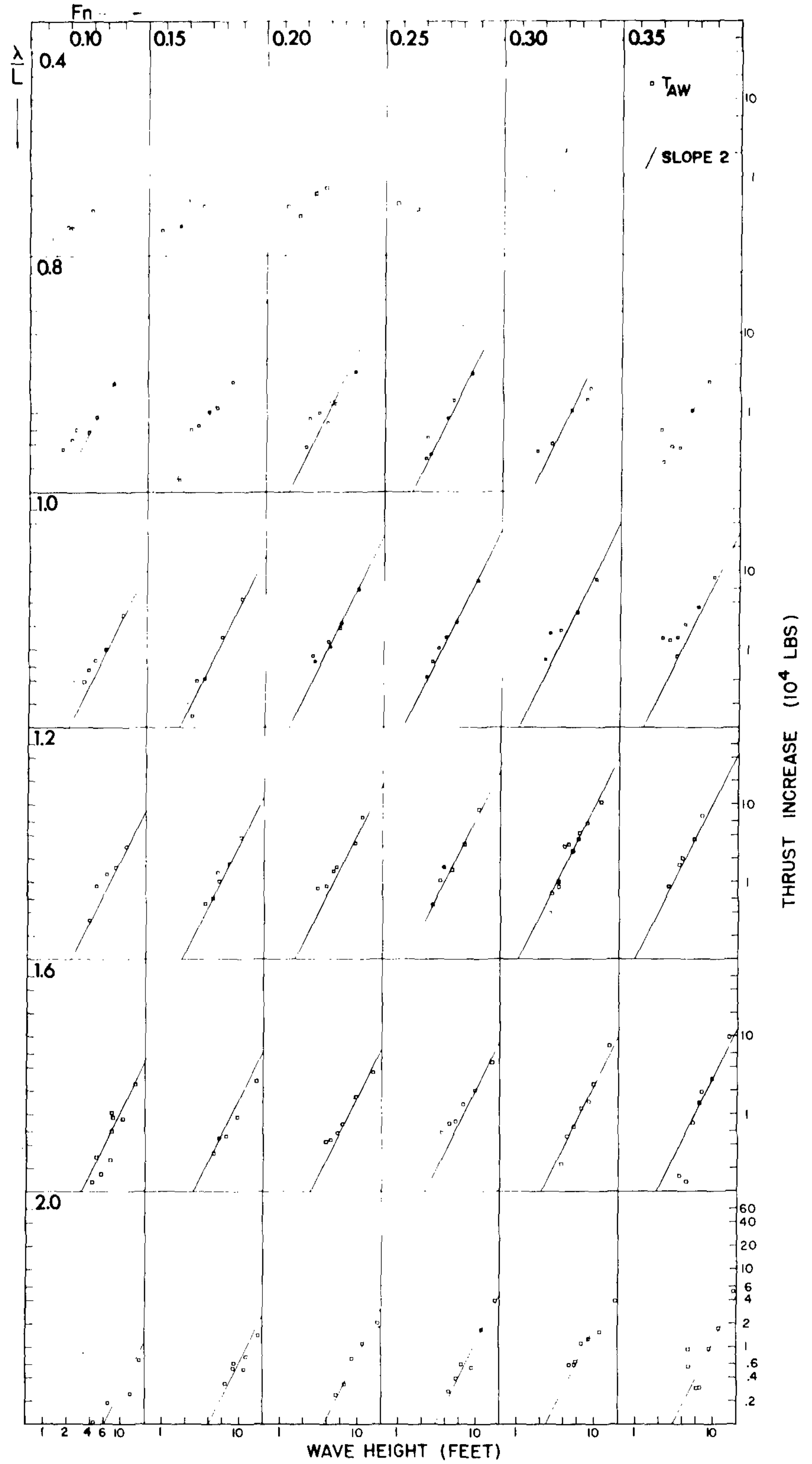

Figure 4 – Added Thrust versus Wave Height for Constant Wave Length and Froude Number

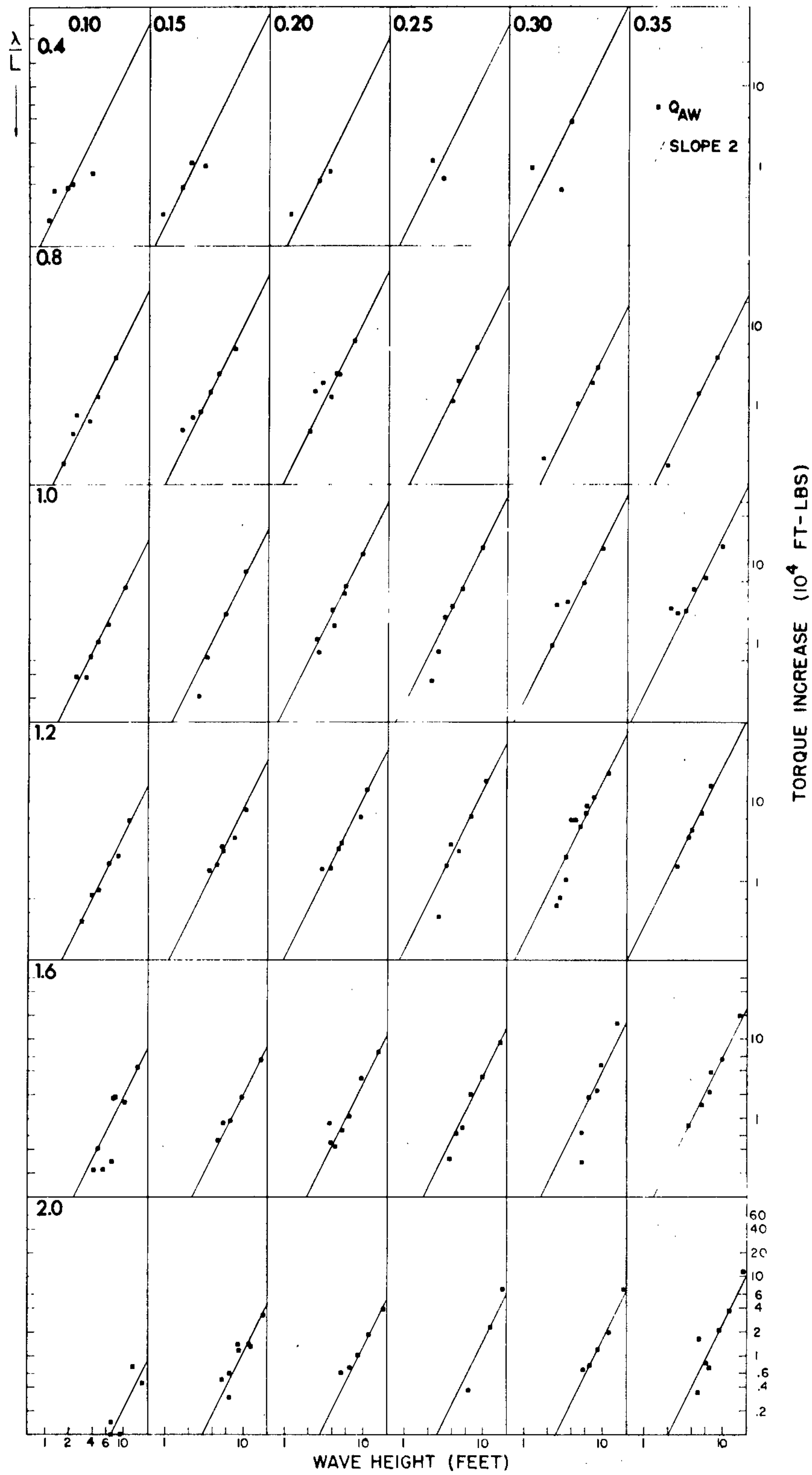

Figure 5 – Added Torque versus Wave Height for Constant Wave Length and Froude Number

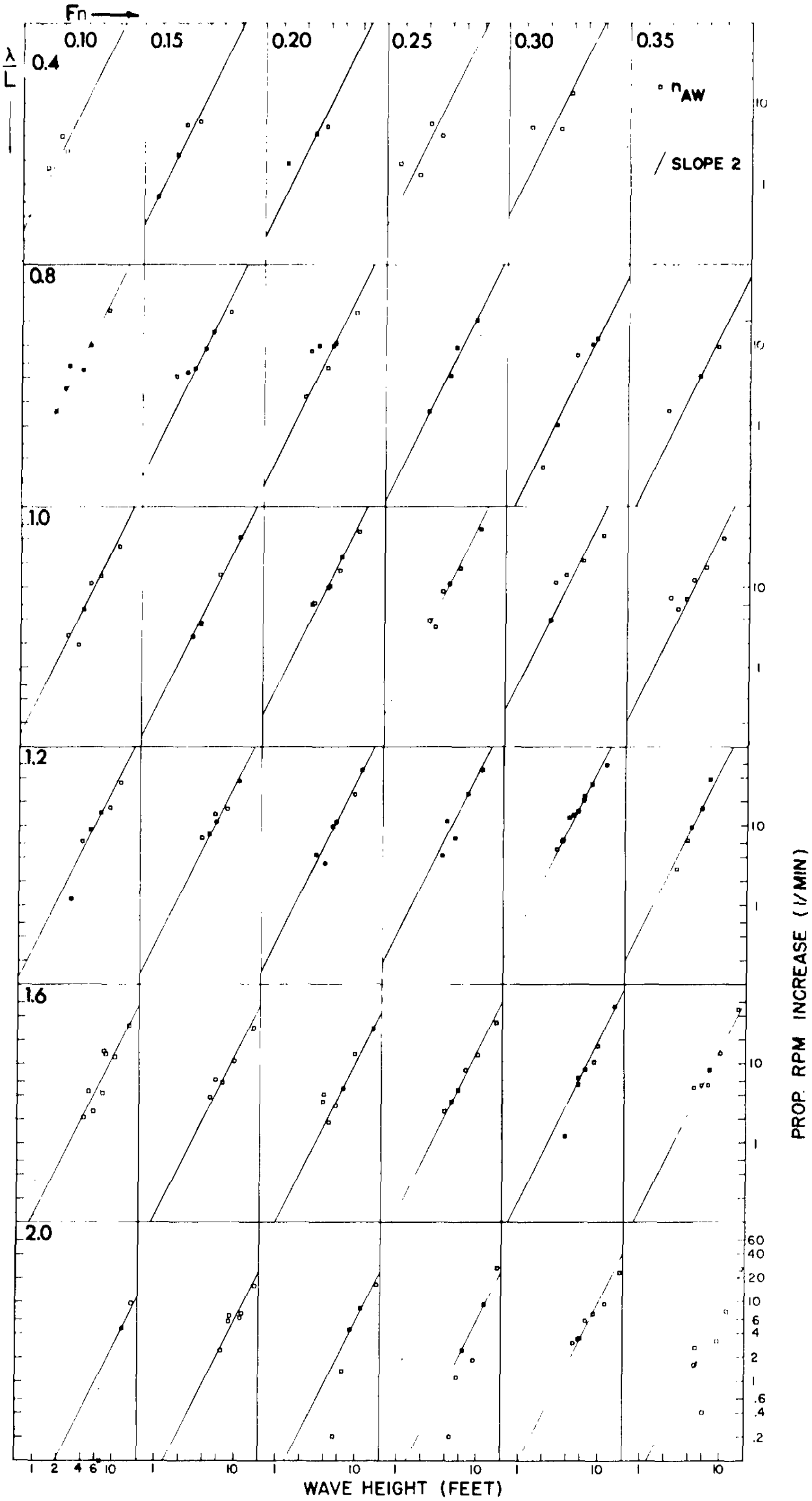

Figure 6 – Added Shaft Speed versus Wave Height for Constant Wave Length and Froude Number

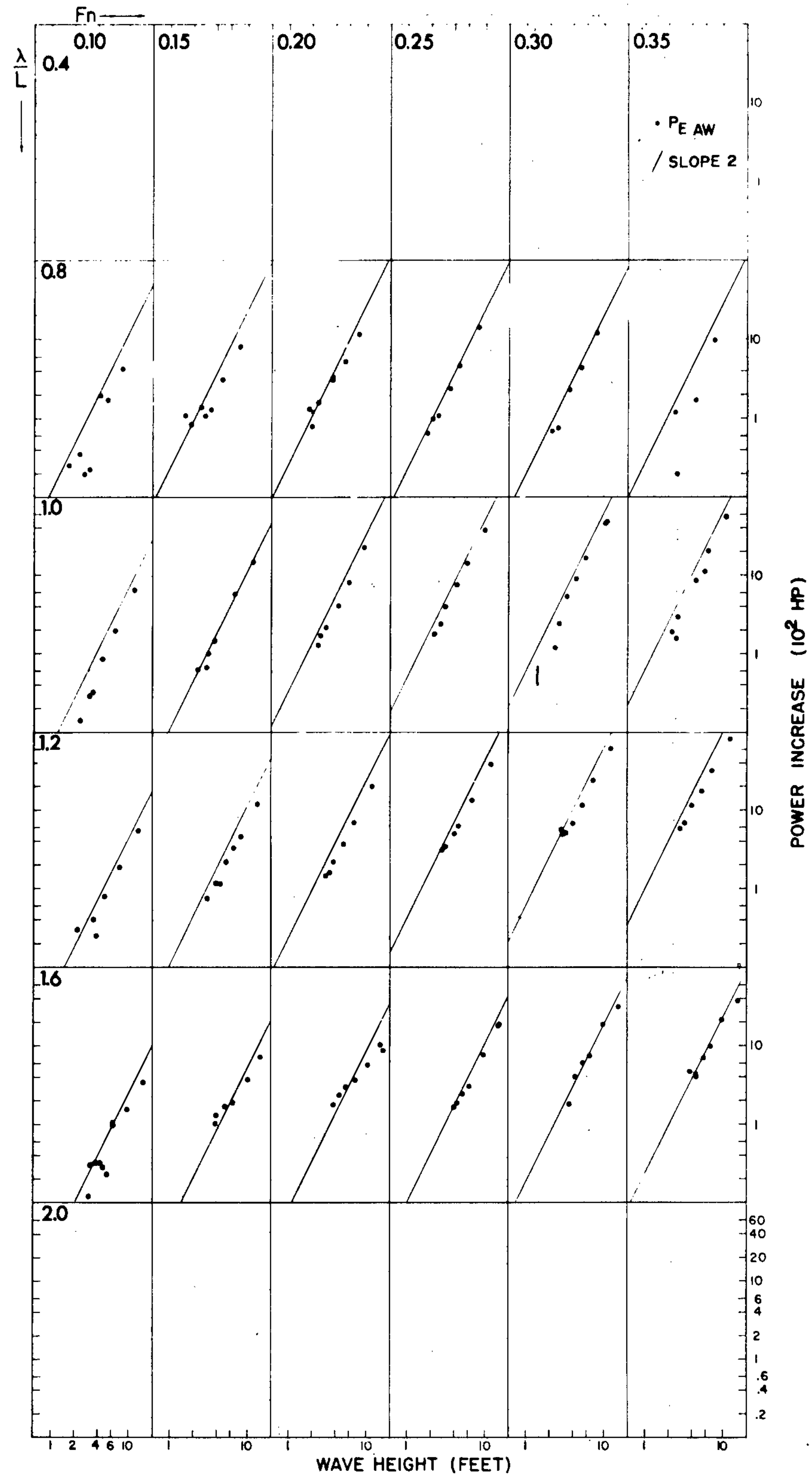

Figure 7 – Added Effective Horsepower versus Wave Height for Constant Wave Length and Froude Number

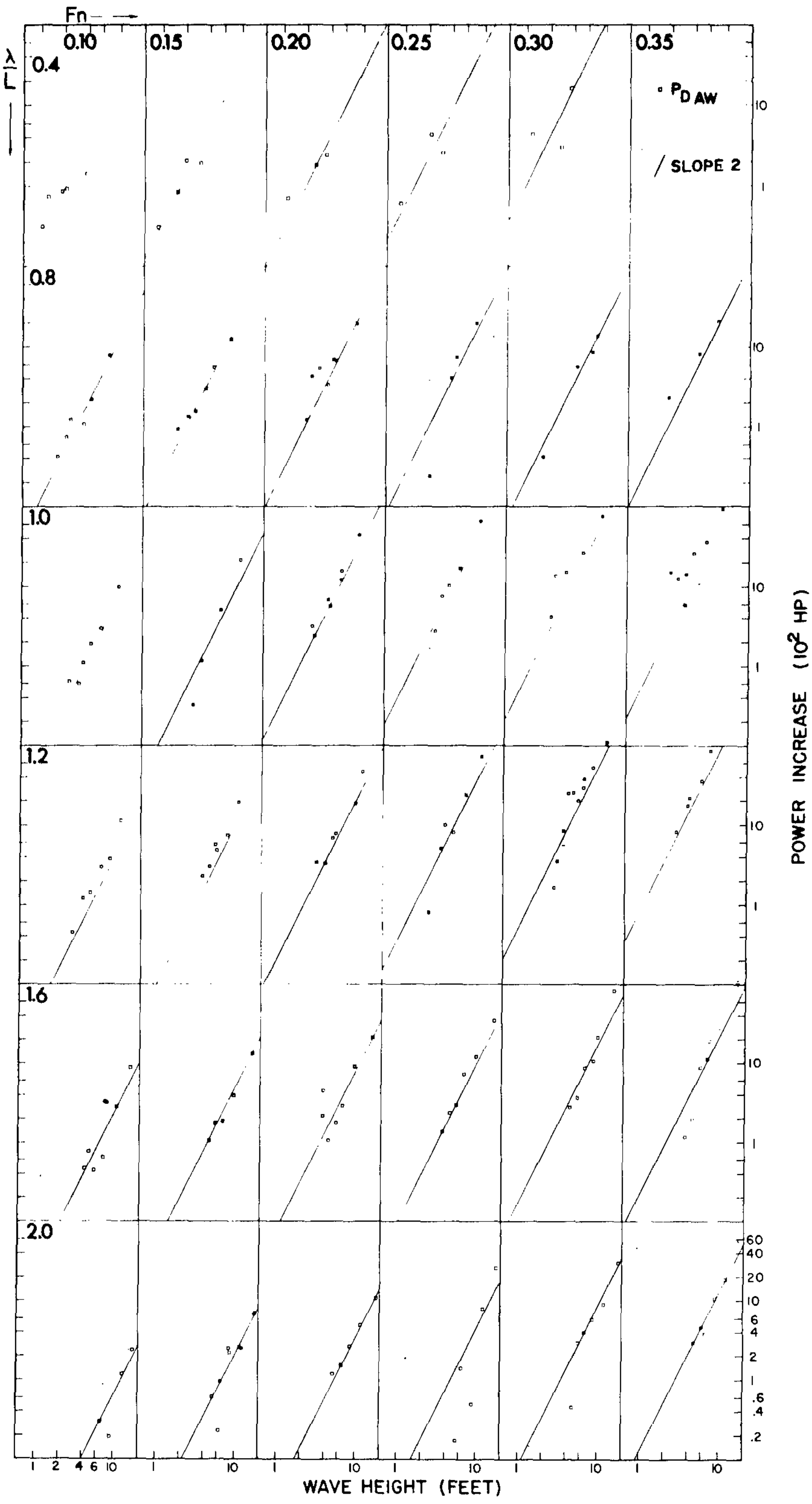

Figure 8 – Added Horsepower versus Wave Height for Constant Wave Length and Froude Number

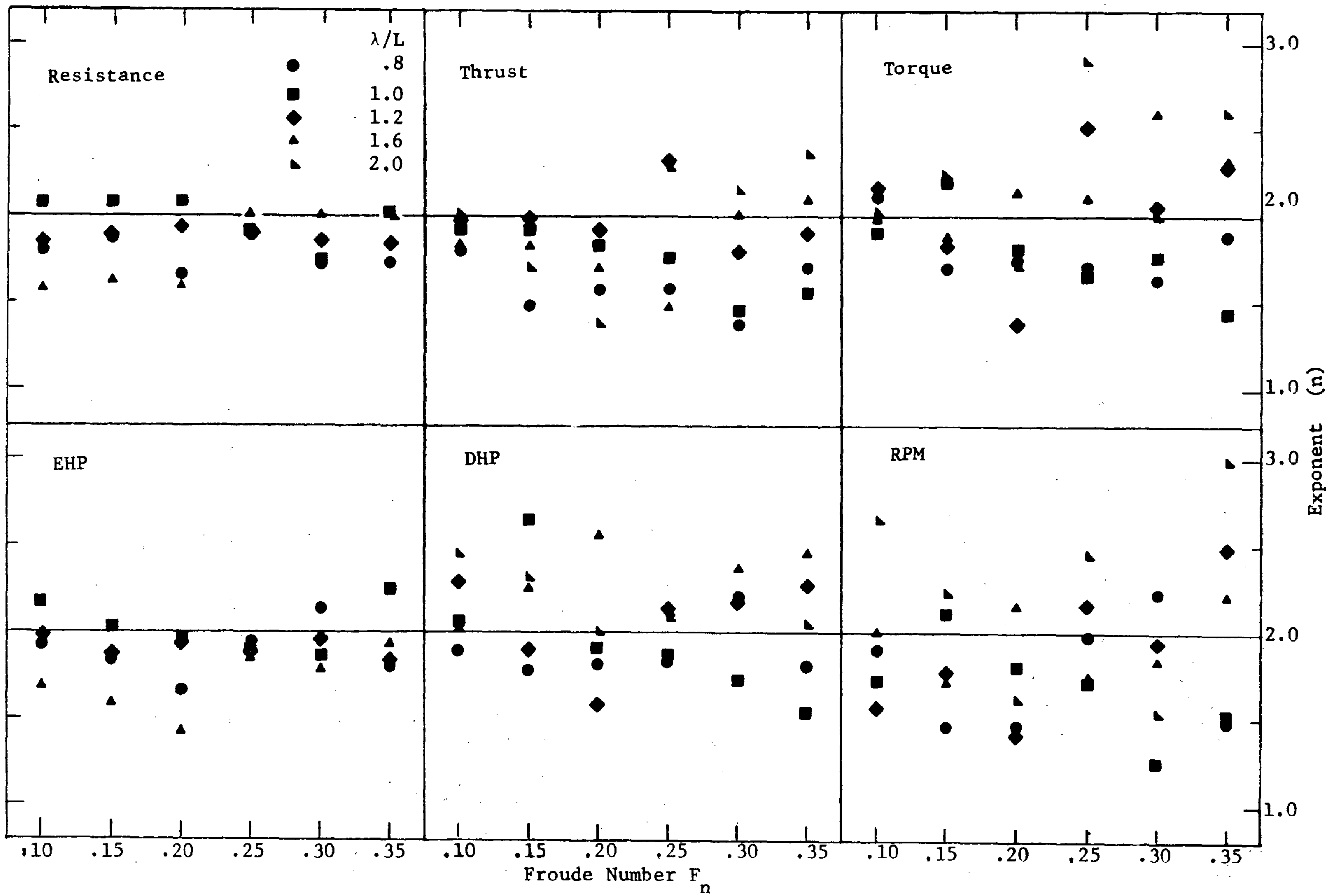

Figure 9 – Exponent (n) for Added Resistance, Thrust, Torque, Shaft Speed, and Power versus Wave Height from Regular Wave Tests

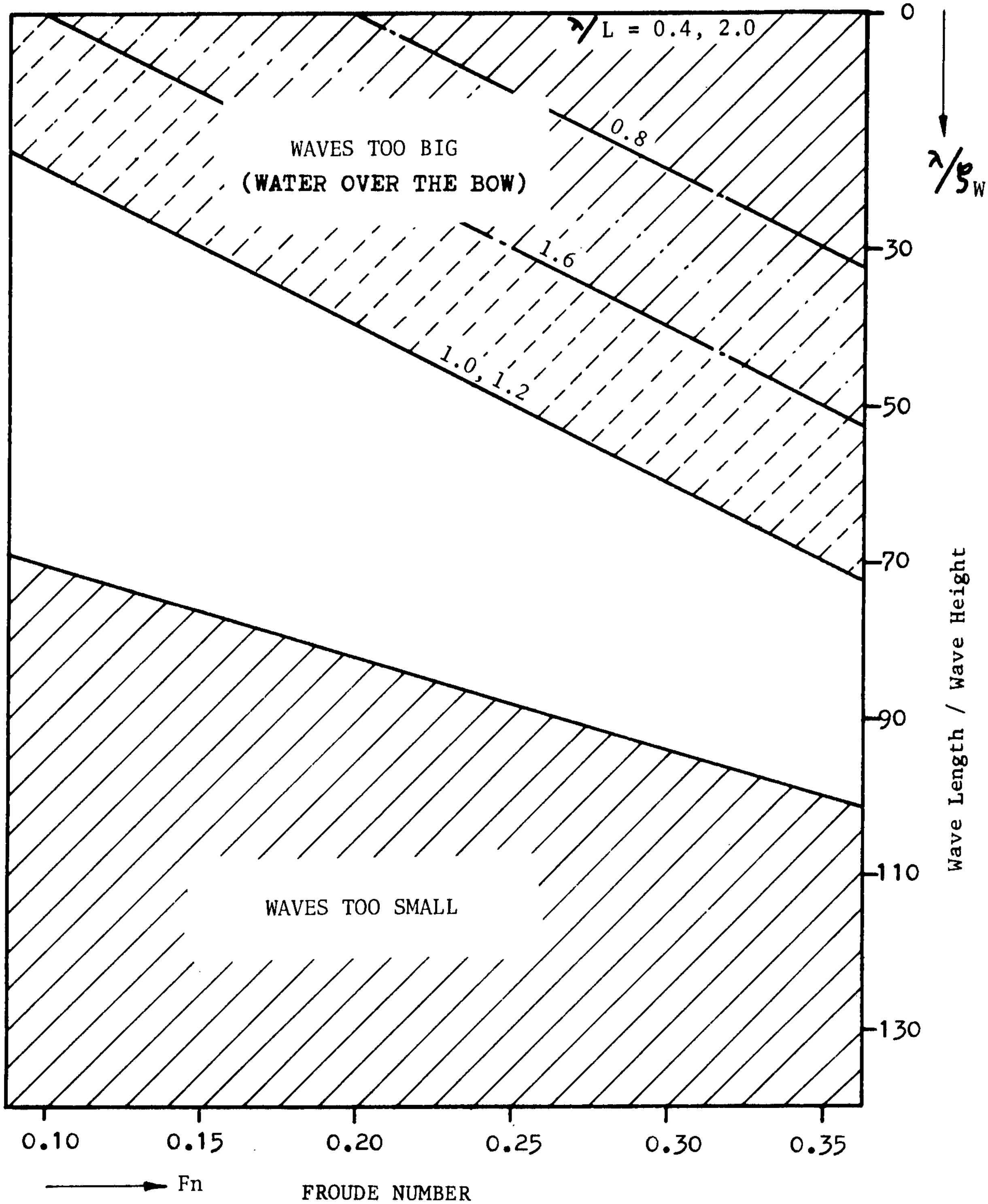

Figure 10 – Limits of Wave Height Used for Various Regular-Wave Experiments

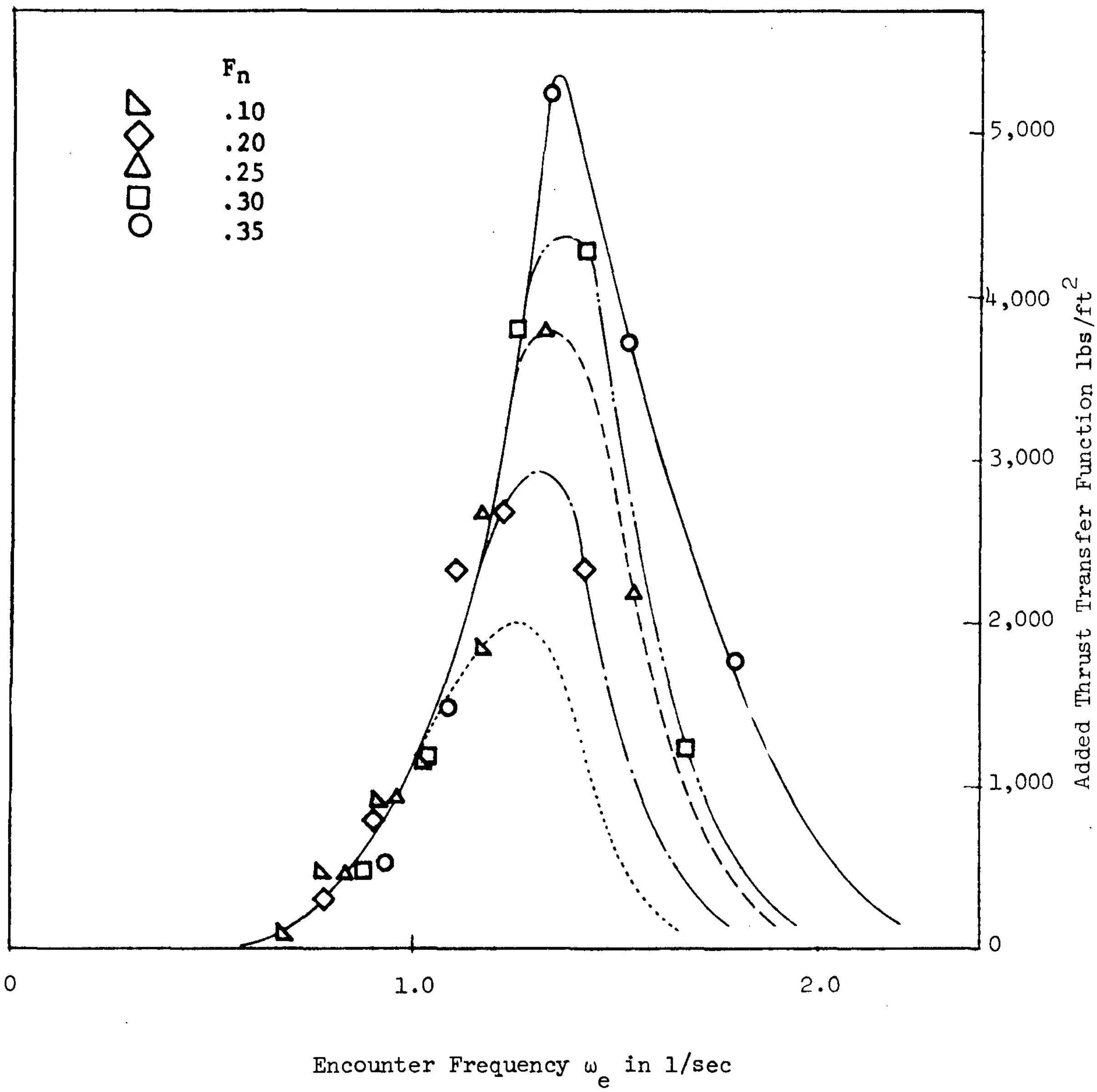

Figure 11 – Nondimensional Transfer Function for Thrust versus Frequency of Encounter

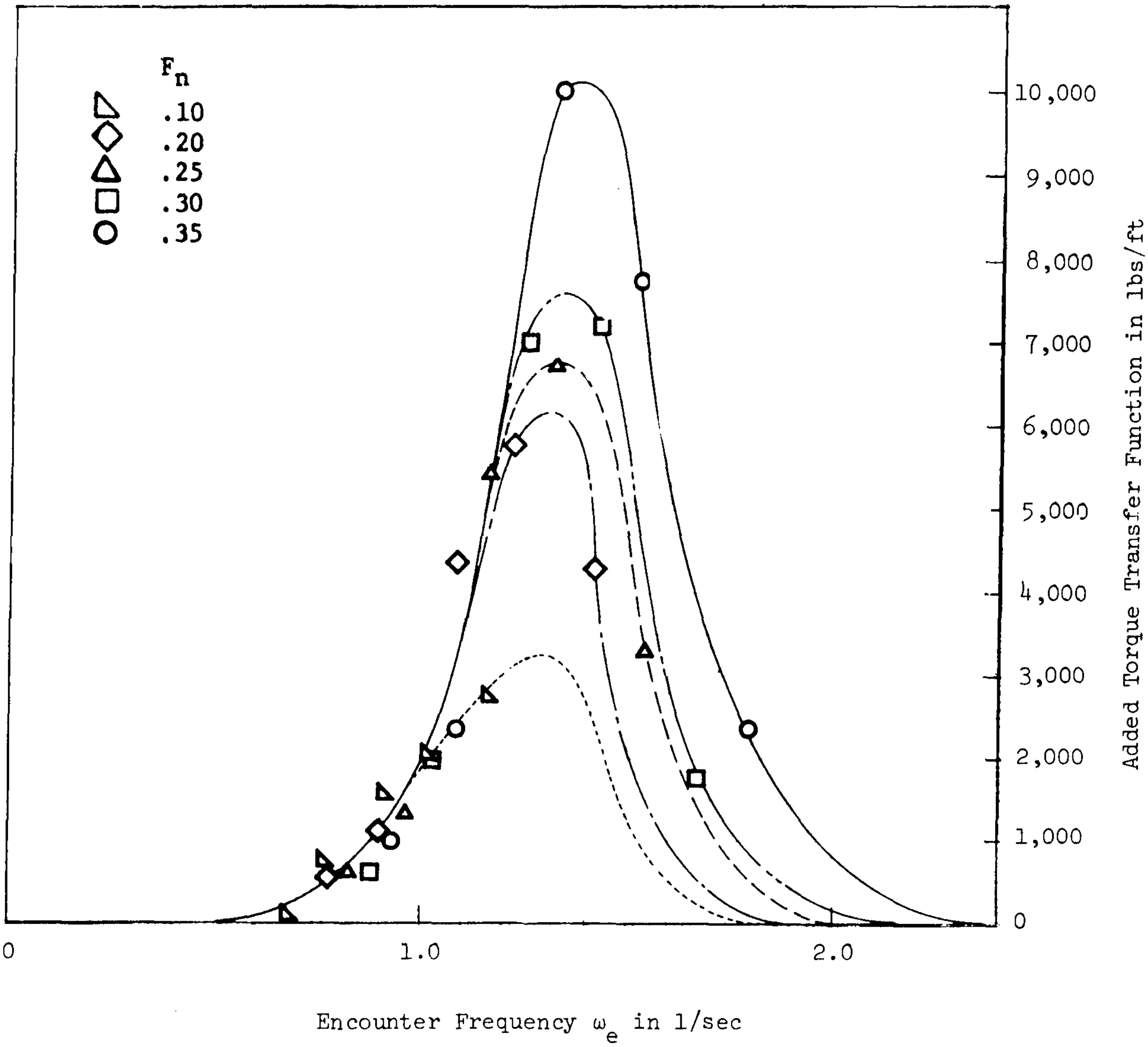

Figure 12 – Nondimensional Transfer Function for Torque versus Frequency of Encounter

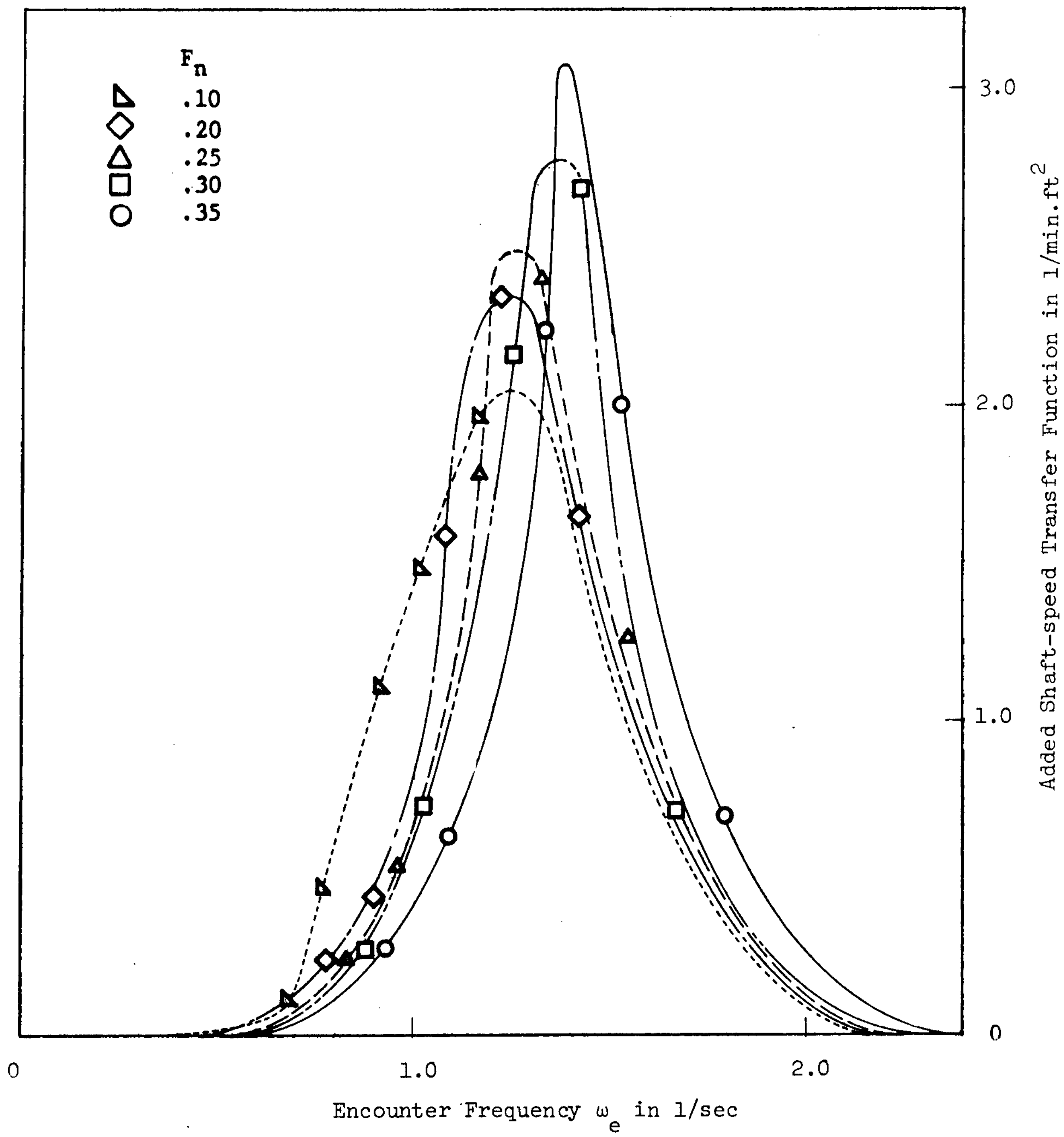

Figure 13 – Nondimensional Transfer Function for Shaft Speed (RPM) versus Frequency of Encounter

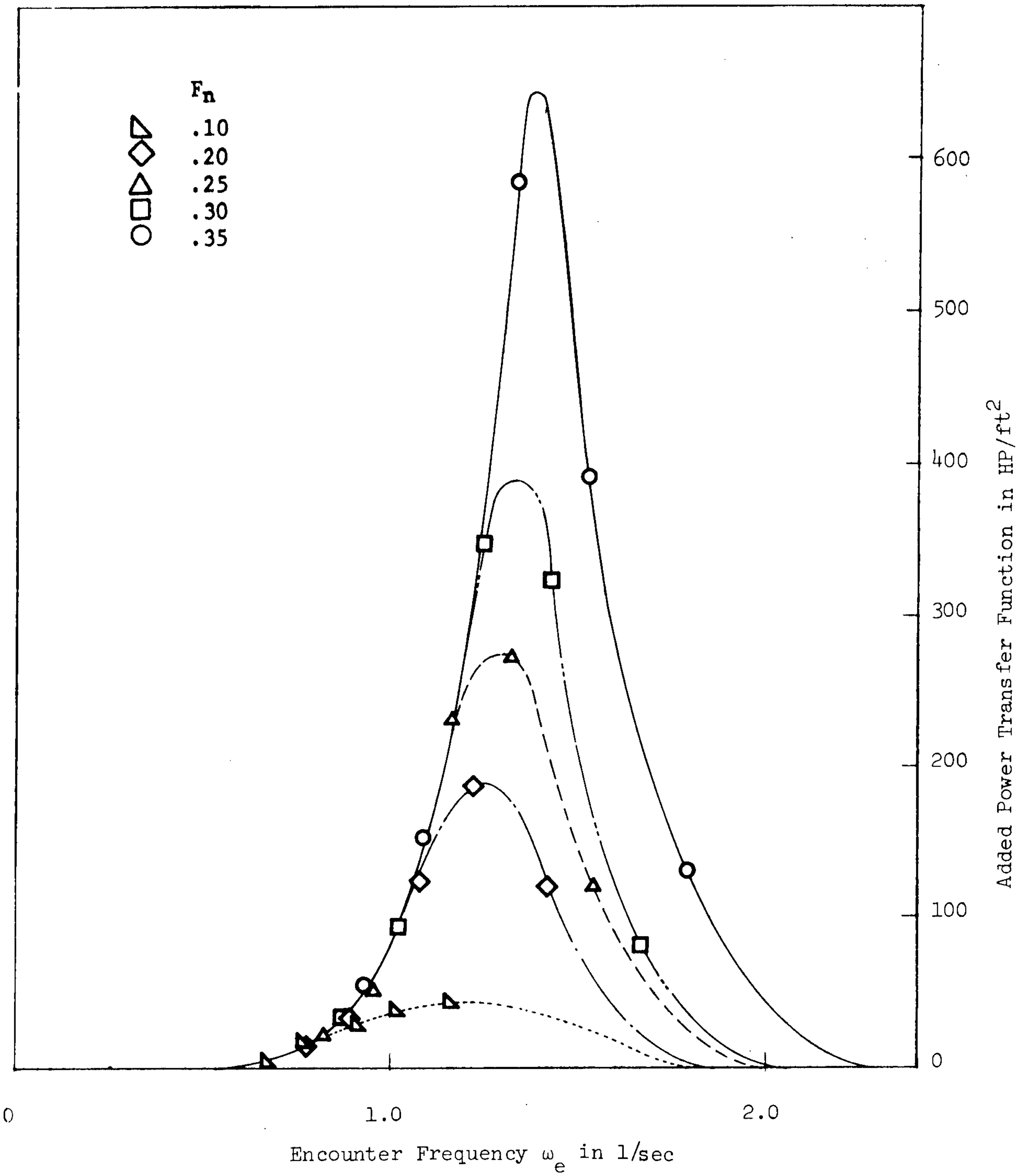

Figure 14 – Nondimensional Transfer Function for Power versus Frequency of Encounter

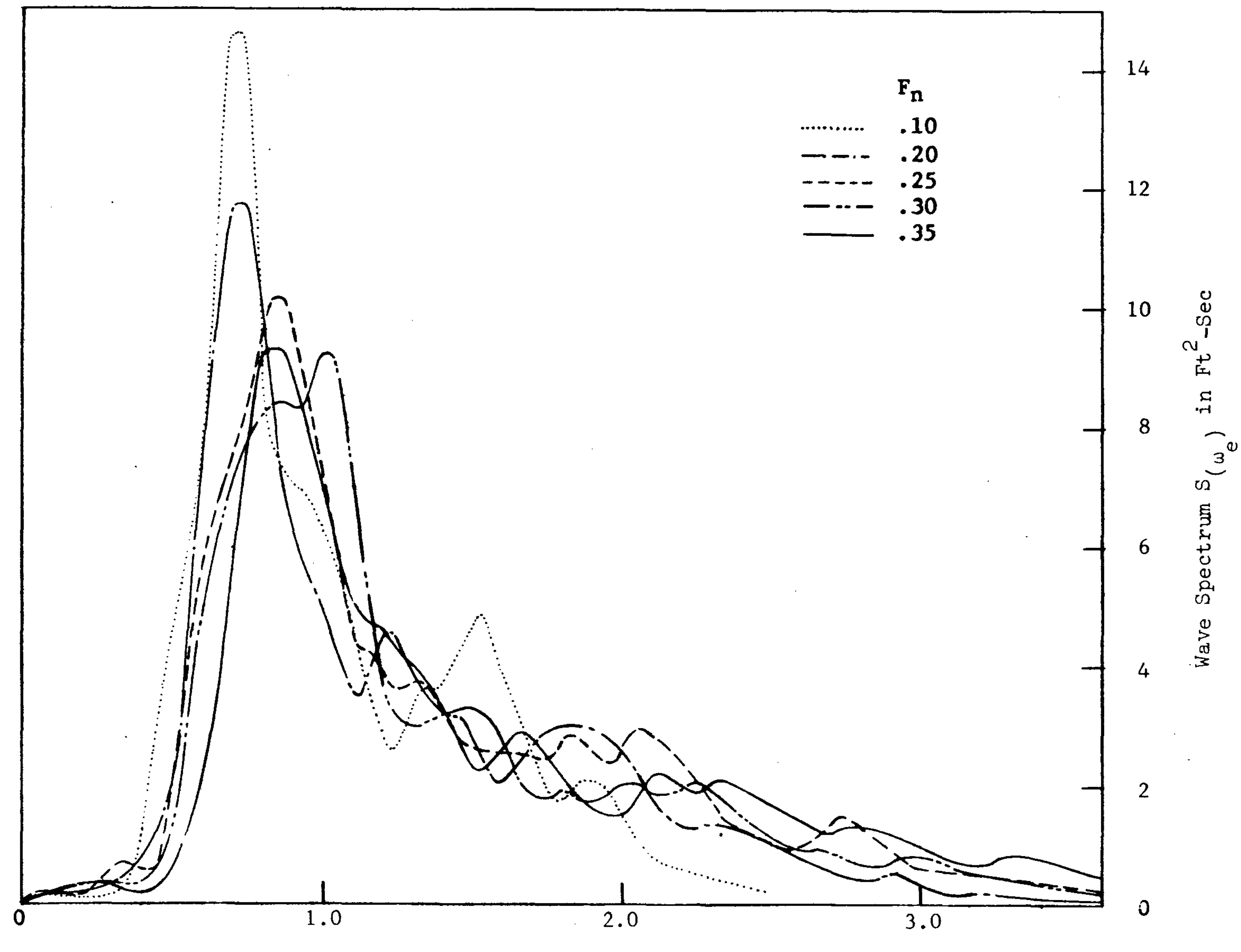

Figure 15 – Measured Sea Spectrum for State 5 Seas

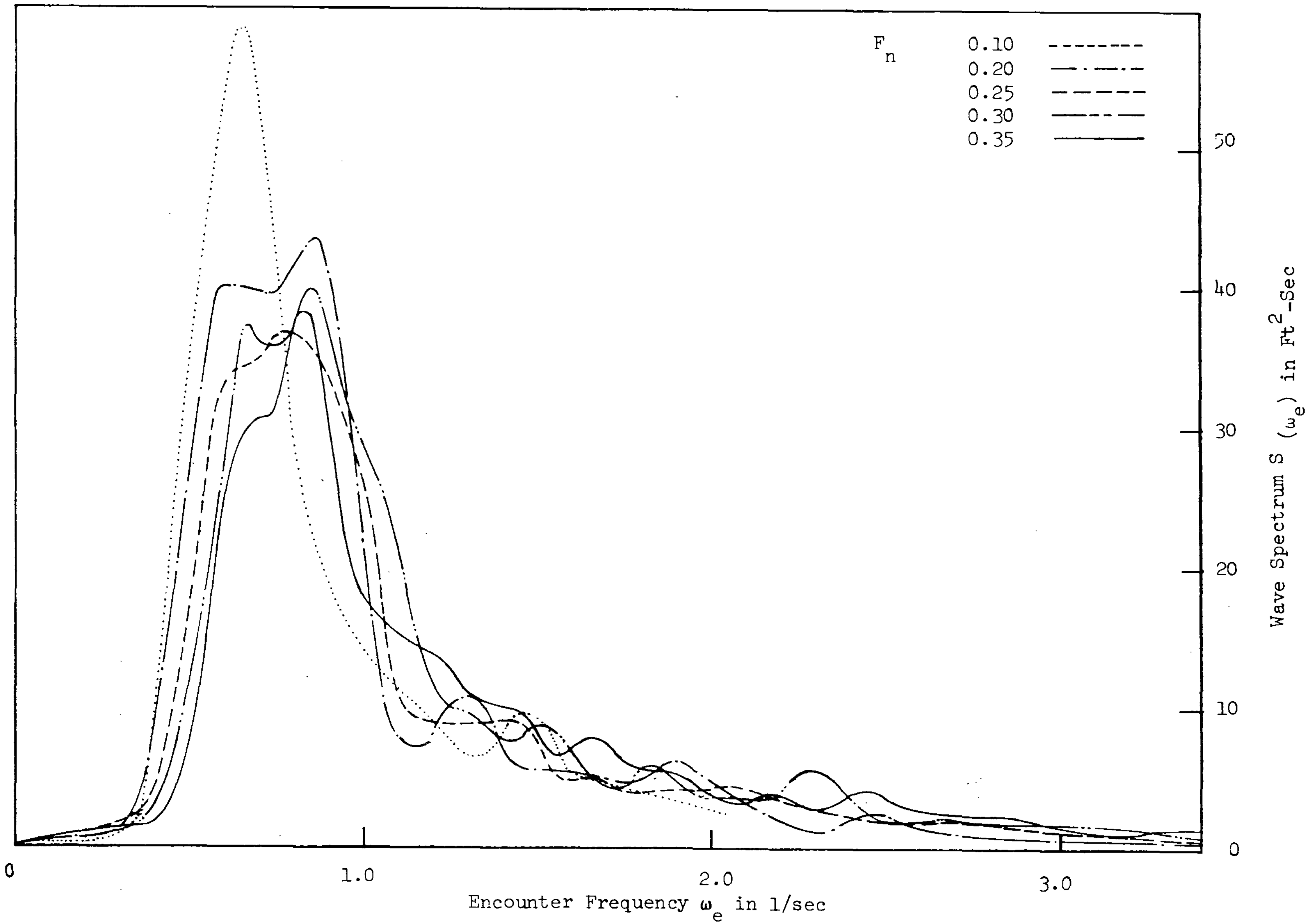

Figure 16 – Measured Sea Spectrum for State 6 Sea

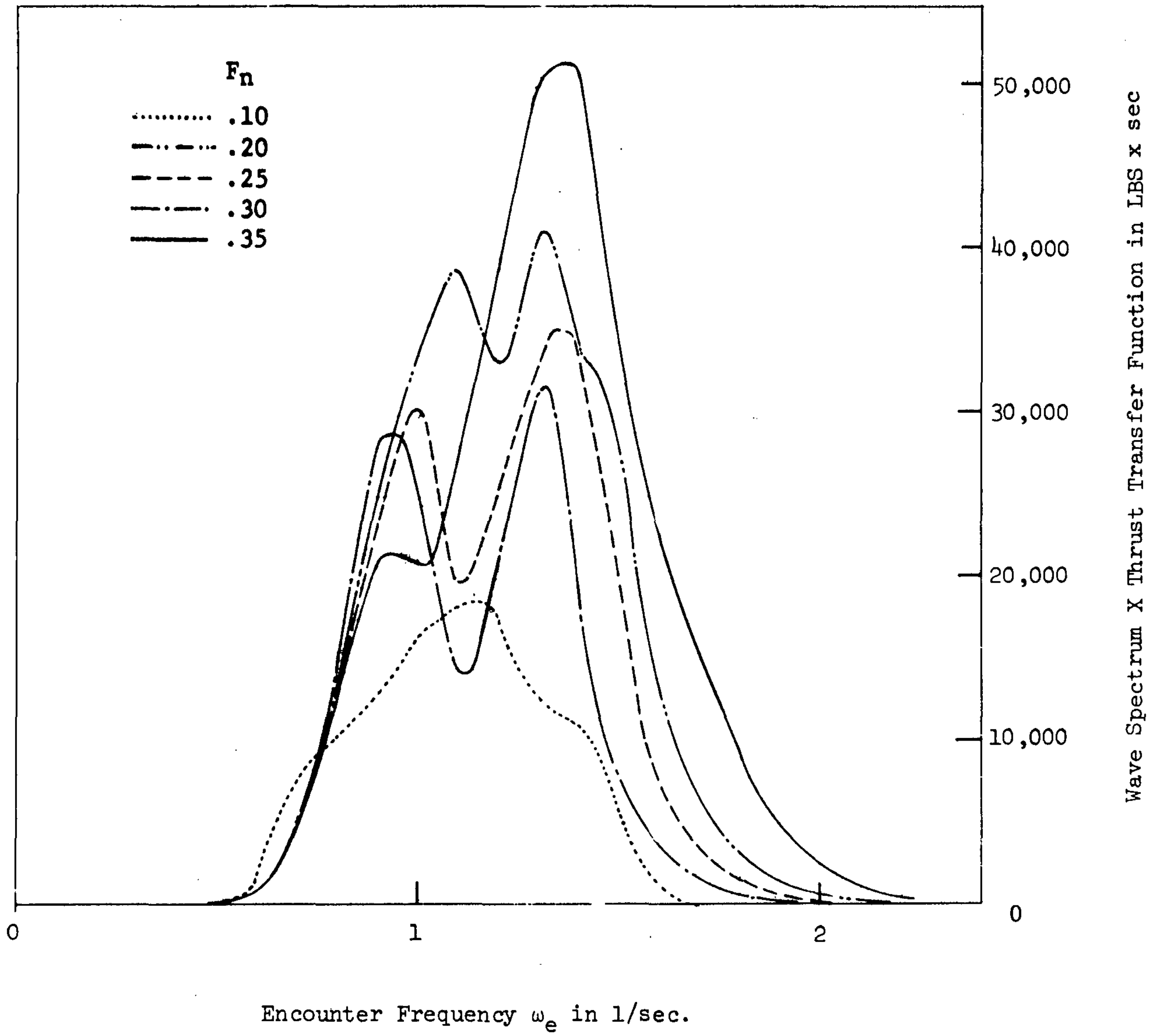

Figure 17 – Typical Product of Sea Spectrum and Transfer Function

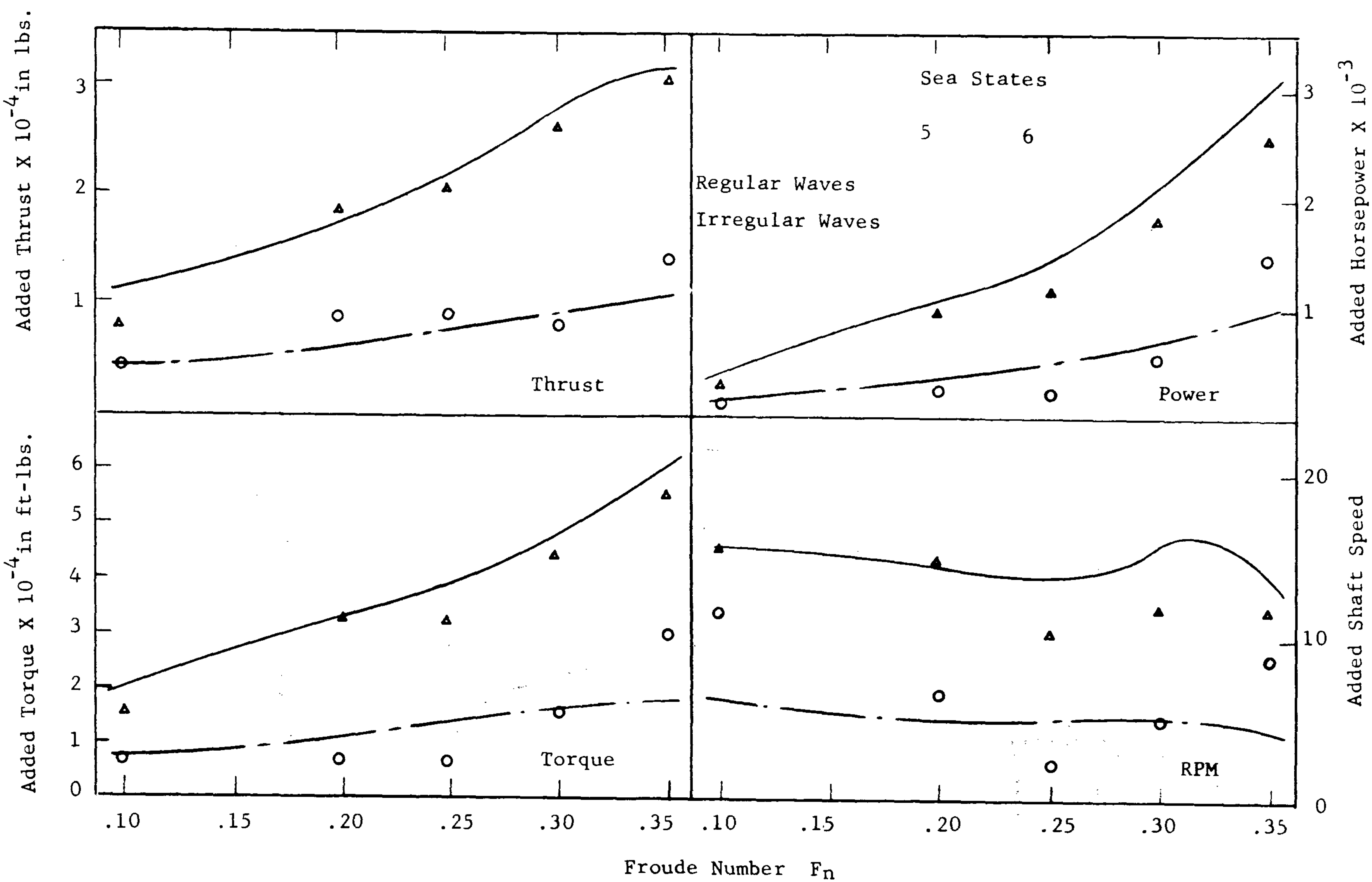

Figure 18 – Predicted Thrust, Torque, Shaft Speed, and Power Increase for Tests in Regular and Irregular Waves, States 5 and 6 Seas

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13. ABSTRACT

Ship powering characteristics in a seaway were investigated for the model of a low-block coefficient, displacement-type hull in both regular and irregular head seas. The increase in power required to maintain speed was predicted by using both the regular-wave and the irregular-wave test results and these predictions were compared. Results indicate that when used within certain limits, the assumption held that added drag is proportional to wave height squared.

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Powering in Waves						
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